

**Chemistry  
Higher level  
Paper 2**

Thursday 14 May 2015 (afternoon)

Candidate session number

2 hours 15 minutes

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**Instructions to candidates**

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all questions.
- Section B: answer two questions.
- Write your answers in the boxes provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for this paper.
- The maximum mark for this examination paper is **[90 marks]**.



### Section A

Answer **all** questions. Write your answers in the boxes provided.

1. Ethanedioic acid is a diprotic acid. A student determined the value of  $x$  in the formula of hydrated ethanedioic acid,  $\text{HOOC}-\text{COOH} \cdot x\text{H}_2\text{O}$ , by titrating a known mass of the acid with a  $0.100 \text{ mol dm}^{-3}$  solution of  $\text{NaOH}(\text{aq})$ .

0.795 g of ethanedioic acid was dissolved in distilled water and made up to a total volume of  $250 \text{ cm}^3$  in a volumetric flask.

$25 \text{ cm}^3$  of this ethanedioic acid solution was pipetted into a flask and titrated against aqueous sodium hydroxide using phenolphthalein as an indicator.

The titration was then repeated twice to obtain the results below.

Volume of $0.100 \text{ mol dm}^{-3} \text{ NaOH} / \text{cm}^3$	Titration 1	Titration 2	Titration 3
Final burette reading ( $\pm 0.05$ )	13.00	25.70	38.20
Initial burette reading ( $\pm 0.05$ )	0.00	13.00	25.70
Volume added			

- (a) Calculate the average volume of  $\text{NaOH}$  added, in  $\text{cm}^3$ , in titrations 2 and 3, and then calculate the amount, in mol, of  $\text{NaOH}$  added.

[2]

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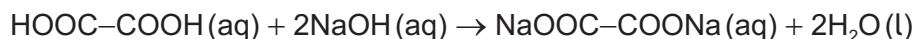
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**(Question 1 continued)**

- (b) (i) The equation for the reaction taking place in the titration is:



Determine the amount, in mol, of ethanedioic acid that reacts with the average volume of NaOH(aq).

[1]

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- (ii) Determine the amount, in mol, of ethanedioic acid present in 250 cm<sup>3</sup> of the original solution.

[1]

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- (iii) Determine the molar mass of hydrated ethanedioic acid.

[1]

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- (iv) Determine the value of x in the formula HOOC-COOH•xH<sub>2</sub>O.

[2]

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- (c) Identify the strongest intermolecular force in solid ethanedioic acid.

[1]

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**(This question continues on the following page)**



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**Turn over**

**(Question 1 continued)**

- (d) Deduce the Lewis (electron dot) structure of ethanedioic acid,  $\text{HOOC}-\text{COOH}$ . [1]

- (e) Predict and explain the difference in carbon-oxygen bond lengths in ethanedioic acid and its conjugate base,  $^-\text{OOC}-\text{COO}^-$ . [3]

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2. This question is about the compounds of some period 3 elements.

- (a) State the equations for the reactions of sodium oxide with water and phosphorus(V) oxide with water. [2]

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- (b) (i) Explain why the melting point of phosphorus(V) oxide is lower than that of sodium oxide in terms of their bonding and structure. [2]

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- (ii) Predict whether phosphorus(V) oxide and sodium oxide conduct electricity in their solid and molten states. Complete the boxes with “yes” or “no”. [2]

	Phosphorus(V) oxide	Sodium oxide
Solid state	.....	.....
Molten state	.....	.....

(This question continues on the following page)



**(Question 2 continued)**

- (c) Predict and explain the pH of the following aqueous solutions, using equations to support your answer.

[4]

Ammonium chloride,  $\text{NH}_4\text{Cl}(\text{aq})$ :

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Sodium methanoate,  $\text{HCOONa}(\text{aq})$ :

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3. The rate of reaction is an important factor in industrial processes such as the Contact process to make sulfur trioxide,  $\text{SO}_3(\text{g})$ .

(a) Define the term *rate of reaction*.

[1]

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(b) Describe the collision theory.

[3]

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(c) The Contact process involves this homogeneous equilibrium:



- (i) State and explain how increasing the pressure of the reaction mixture affects the yield of  $\text{SO}_3$ .

[2]

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(This question continues on the following page)



**(Question 3 continued)**

- (ii) 2.00 mol of  $\text{SO}_2(\text{g})$  are mixed with 3.00 mol of  $\text{O}_2(\text{g})$  in a  $1.00\text{ dm}^3$  container until equilibrium is reached. At equilibrium there are 0.80 mol of  $\text{SO}_3(\text{g})$ .

Determine the equilibrium constant ( $K_c$ ) assuming all gases are at the same temperature and pressure.

[4]

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- (iii) State the effect of increasing temperature on the value of  $K_c$  for this reaction.

[1]

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- (d) Outline the economic importance of using a catalyst in the Contact process.

[2]

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4. Copper is a metal that has been used by humans for thousands of years.

(a) State the full electron configuration of  $^{65}\text{Cu}$ . [1]

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(b) State one difference in the physical properties of the isotopes  $^{63}\text{Cu}$  and  $^{65}\text{Cu}$  and explain why their chemical properties are the same. [2]

Physical:

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Chemical:

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(c) Describe the bonding in solid copper. [2]

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## Section B

Answer **two** questions. Write your answers in the boxes provided.

5. Ethanol has many industrial uses.

- (a) State an equation for the formation of ethanol from ethene and the necessary reaction conditions.

[3]

Equation:

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Conditions:

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- (b) (i) Define the term *average bond enthalpy*.

[2]

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- (ii) Ethanol can be used as a fuel. Determine the enthalpy of combustion of ethanol at 298 K, in  $\text{kJ mol}^{-1}$ , using the values in table 10 of the data booklet, assuming all reactants and products are gaseous.

[4]

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**(Question 5 continued)**

- (c) Students can also measure the enthalpy of combustion of ethanol in the laboratory using calorimetry. Suggest the major source of systematic error in these procedures. [1]

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- (d) State the equation for the acid-catalysed reaction of ethanol with propanoic acid and state the name of the organic product. [2]

Equation:

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Name of the organic product:

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- (e) (i) A polyester can be formed when ethane-1,2-diol reacts with benzene-1,4-dicarboxylic acid.

Deduce the structure of the repeating unit and state the other product formed. [2]

Repeating unit:

Other product:

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**(This question continues on the following page)**



(Question 5 continued)

- (ii) State the type of polymerization that occurs. [1]

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- (f) (i) The standard enthalpy change of combustion,  $\Delta H_c^\ominus$ , of propanoic acid is  $-1527 \text{ kJ mol}^{-1}$ . Determine the standard enthalpy change of formation of propanoic acid, in  $\text{kJ mol}^{-1}$ , using this information and data from table 12 of the data booklet. [4]

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- (ii) Deduce, giving a reason, the sign of the standard entropy change of the system for the formation of propanoic acid from its elements. [2]

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- (g) Identify **three** allotropes of carbon and describe their structures. [4]

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6. Bromomethane was used as a pesticide until it was found to be ozone-depleting.

(a) State the equation for the reaction between methane and bromine to form bromomethane. [1]

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(b) (i) Explain, using equations, the complete free-radical mechanism for the reaction of methane with bromine, including necessary reaction conditions. [4]

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(ii) Bromomethane reacts with aqueous sodium hydroxide. State the organic product of this reaction. [1]

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(c) Explain why the rate of the reaction between iodomethane,  $\text{CH}_3\text{I}$ , and  $\text{NaOH(aq)}$  is faster than the rate of the reaction between  $\text{CH}_3\text{Br}$  and  $\text{NaOH(aq)}$ . [2]

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**(Question 6 continued)**

- (d) (i) Bromine can be produced by the electrolysis of **molten** sodium bromide. Deduce the half-equation for the reaction at each electrode.

[2]

Positive electrode (anode):

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Negative electrode (cathode):

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- (ii) Predict the products formed at the electrodes during the electrolysis of concentrated **aqueous** sodium bromide.

[2]

Positive electrode (anode):

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Negative electrode (cathode):

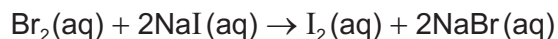
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**(Question 6 continued)**

- (e) Bromine reacts with aqueous sodium iodide.



Identify the oxidizing agent in this reaction.

[1]

- (f) (i) Define the term *standard electrode potential*,  $E^\ominus$ .

[1]

- (ii) Draw a labelled diagram for the voltaic cell in which the following reaction occurs.



Include in your answer the direction of electron flow and the polarity of the electrodes.

[4]

**(This question continues on the following page)**



**(Question 6 continued)**

- (iii) A student measures a voltage of 2.65 V in the voltaic cell formed between magnesium and copper half-cells using a digital voltmeter.

State the random uncertainty of this value, in V, and the number of significant figures in the answer.

[2]

Random uncertainty:

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Significant figures:

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- (iv) Outline how the student can reduce the random error in her results.

[1]

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- (g) Determine the standard enthalpy change of formation,  $\Delta H_f^\ominus$ , of NaCl(s), in  $\text{kJ mol}^{-1}$ , using a Born-Haber cycle and tables 7, 10 and 13 of the data booklet. The standard enthalpy change of atomization (standard enthalpy change of sublimation),  $\Delta H_{\text{at}}^\ominus$ , of Na(s) is  $+108 \text{ kJ mol}^{-1}$ .

[4]

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7. (a) (i) Ethanol is a primary alcohol that can be oxidized by acidified potassium dichromate(VI). Distinguish between the reaction conditions needed to produce ethanal and ethanoic acid. [2]

Ethanal:

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Ethanoic acid:

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- (ii) Determine the oxidation number of carbon in ethanol and ethanal. [2]

Ethanol:

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Ethanal:

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- (iii) Deduce the half-equation for the oxidation of ethanol to ethanal. [1]

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- (iv) Deduce the overall redox equation for the reaction of ethanol to ethanal with acidified potassium dichromate(VI). [2]

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**(Question 7 continued)**

- (b) Ethanol can be made by reacting aqueous sodium hydroxide with bromoethane. Explain the mechanism for this reaction, using curly arrows to represent the movement of electron pairs. [4]

- (c) (i) Determine the orders of reaction of the reactants and the overall rate expression for the reaction between 2-bromobutane and aqueous sodium hydroxide using the data in the table.

Experiment	[NaOH] / mol dm <sup>-3</sup>	[C <sub>4</sub> H <sub>9</sub> Br] / mol dm <sup>-3</sup>	Rate / mol dm <sup>-3</sup> s <sup>-1</sup>
1	1.00	1.00	1.66 × 10 <sup>-3</sup>
2	0.50	1.00	8.31 × 10 <sup>-4</sup>
3	0.25	0.25	1.02 × 10 <sup>-4</sup>
4	1.00	0.50	8.29 × 10 <sup>-4</sup>

[2]

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**(Question 7 continued)**

- (ii) Determine the rate constant,  $k$ , with its units, using the data from experiment 3. [2]

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- (iii) Identify the molecularity of the rate-determining step in this reaction. [1]

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- (d) 2-bromobutane exists as optical isomers.

- (i) State the essential feature of optical isomers. [1]

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- (ii) Outline how a polarimeter can distinguish between these isomers. [2]

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- (e) Describe, using an equation, the elimination of HBr from 2-bromobutane, stating the reagent used. [2]

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**(Question 7 continued)**

- (f) Describe the formation of  $\sigma$  and  $\pi$  bonds in an alkene. [2]

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- (g) The two most abundant isotopes of bromine have the mass numbers 79 and 81. Calculate the relative abundance of  $^{79}\text{Br}$  using table 5 of the data booklet, assuming the abundance of the other isotopes is negligible. [2]

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8. Acids can be described as strong or weak.

- (a) (i) Outline the difference in dissociation between strong and weak acids of the same concentration. [1]

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- (ii) Describe **three** tests that can be carried out in the laboratory, and the expected results, to distinguish between  $0.10 \text{ mol dm}^{-3} \text{ HCl(aq)}$  and  $0.10 \text{ mol dm}^{-3} \text{ CH}_3\text{COOH(aq)}$ . [3]

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- (b) Calculate the pH, using table 15 of the data booklet, of a solution of ethanoic acid made by dissolving 1.40 g of the acid in distilled water to make a  $500 \text{ cm}^3$  solution. [4]

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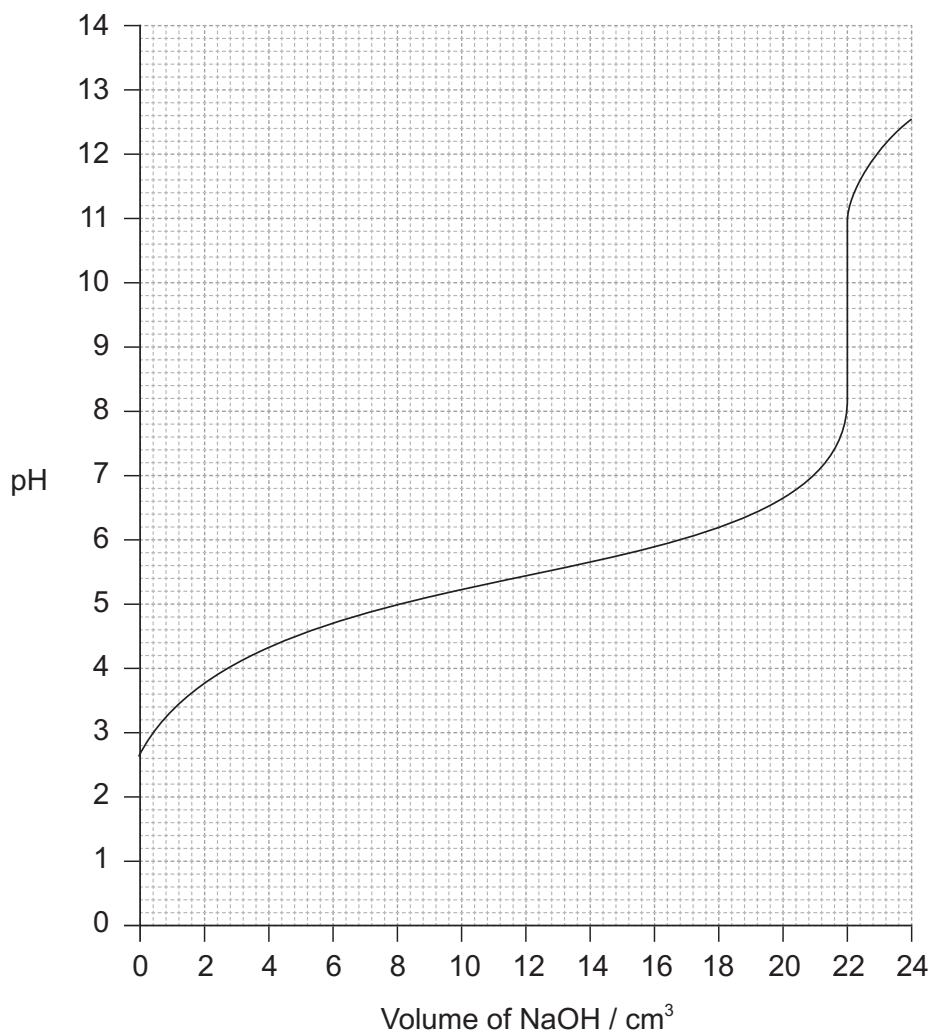
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(Question 8 continued)

- (c) (i) Determine the pH at the equivalence point of the titration and the  $pK_a$  of an unknown acid using the acid-base titration curve below.

[3]



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- (ii) Identify, using table 16 of the data booklet, a suitable indicator to show the end-point of this titration.

[1]

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(This question continues on the following page)



**(Question 8 continued)**

- (iii) Describe how an indicator, that is a weak acid, works. Use Le Chatelier's principle in your answer. [2]

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- (d) (i) State the formula of the conjugate base of chloroethanoic acid,  $\text{CH}_2\text{ClCOOH}$ . [1]

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- (ii) Identify, with a reason, whether chloroethanoic acid is weaker or stronger than ethanoic acid using table 15 of the data booklet. [1]

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**(This question continues on the following page)**



(Question 8 continued)

- (iii) Determine the pH of the solution resulting when  $100\text{ cm}^3$  of  $0.50\text{ mol dm}^{-3}$   $\text{CH}_2\text{ClCOOH}$  is mixed with  $200\text{ cm}^3$  of  $0.10\text{ mol dm}^{-3}$   $\text{NaOH}$ . [4]

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- (e) Describe how chlorine's position in the periodic table is related to its electron arrangement. [2]

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- (f)  $\text{SCl}_2$  and  $\text{SClF}_5$  are two sulfur chloride type compounds with sulfur having different oxidation states. Predict the name of the shape, the bond angle and polarity of these molecules. [3]

Molecule	Shape	Bond angle	Polarity
$\text{SCl}_2$	.....	.....	.....
$\text{SClF}_5$	.....	.....	.....

